Dwell Time of Shinguards over One Season in College, High School, and Youth Female Soccer Players

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DEDICATION

This project is dedicated to my family. Without your help and assistance I would not have been in this position today. I am grateful for everything you have done for me in helping me get where I am. I especially want to thank my husband Thomas for your support along the way. Thank you for being understanding of the time commitment this project has taken away from our time together. I love you always.

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Melissa Zimmerman

DWELL TIME OF SHINGUARDS OVER ONE SEASON IN COLLEGE, HIGH SCHOOL, AND YOUTH FEMALE SOCCER PLAYERS

Many studies have been performed on the ability and effectiveness of shinguards to dissipate force. These studies have shown that shinguards can reduce force thus reduce injury; however, none have evaluated how long shinguards are effective. The purpose of this study was to determine if the amount of usage that a shinguard gets over time is detrimental to its ability to dissipate force. There were 36 participants recruited for this study from three different female soccer teams; Division I, high school, and a youth team. Twenty seven participants completed the study. Subjects were divided into 14 participants in the older age group, high school and college, and 13 participants in the younger age group the youth team. Each participant received a pair of Adidas Adi shinguards (ADIDAS, Spartanburg, SC). Baseline tests of all shinguards occurred before handing them out to the participants. Shinguards were collected from the teams on four occasions: ¼, ½, ¾ of the way through the season, and after post-season. Fifteen pairs of control shinguards were not used by the participants but tested on each occasion. A drop track consisting of a 5kg weight was used to test the shinguards. The weight was dropped from a height of 40cm. An accelerometer (Biopac Systems, Inc, Tri-Axial SS26-2, Goleta, CA) was attached to record data. The shinguards were strapped to a wooden model leg. The 5kg weight was raised and dropped onto the center of each shinguard five times on five separate occasions for a total of 25 hits. Dwell time, the amount of time the weight is in contact with the shinguard during each impact in milliseconds (ms), was calculated for each trial. A repeated measure ANOVA was used to identify any changes over time. A priori alpha level was set at $p<0.05$.

The primary finding in this study was that dwell time did not significantly change through the course of one season. The RMANOVA revealed no significant difference between testing sessions, ($F_{4,244} = 2.15$, $p = 0.08$), between groups ($F_{2,61} = 0.34$, $p = 0.72$), and no time by group interaction ($F_{8,244} = 0.56$, $p = 0.81$). Based on these findings, we can conclude that shinguards do not degrade, as measured by dwell time, over one season. It is best to follow manufacturers guidelines and purchase shinguards when the old ones are broken, deformed, or missing any pieces.

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INTRODUCTION

Soccer is the most participated sport in the world.[1,2] It is also the fastest growing team sport in the United States by male and female athletes alike.[2] There are over 250 million licensed players across 204 countries.[1] It is a contact sport, thus, minor injuries are common, especially in the lower extremity.[2-11] Most soccer injuries are caused by player to player contact whether in practice or in games.[4] The majority of injuries are to soft tissue structures and include sprains, strains, contusions and lacerations.[4,11] Fractures can also occur but do so at a much lower rate.[12]

Starting in 1990, Fédération Internacionale de Football Association (FIFA) mandated the use of shinguards during soccer matches to potentially reduce the number of injuries to the lower extremity, in particular the shin.[1] As of now, shinguards are the only required protective device used in soccer.[13] Shinguards, which are made of a hard rigid outer shell and a soft inner foam layer[14,15] can help protect the shin from soft tissue and bony injuries.[1,4,5,12,16-19] Protective equipment, like shinguards, work best when they are standardized, fit correctly, and not altered.[20] Standardization of shinguards comes from regulation by the National Operating Committee on Standards of Athletic Equipment (NOCSAE) who now require their use at the high school level.[21] The correct fit of a shinguard is based on the athlete's height.[20] The shinguard should lay on the skin such that it is molded to the curvature of the leg.[22] Fitting a shinguard properly can assist in reducing the rate of most injuries.[10] It is up to the coaches and athletic trainers to make sure the equipment is properly fitted and worn by the athletes.[23]

Shinguards reduce injury by acting as shock absorbers and spreading the load across a larger area.[1,12,24,25] The load is then transferred to the surrounding musculature of the lower leg.[14,25] Currently, only a limited number of studies have evaluated shinguards and their ability to dissipate force under a variety of conditions.[3,12,17,24-26] A drop track or pendulum apparatus to create an impact on the shinguards was used in most studies.[12,17,24-26] A drop track typically consists of a weight, 4-7.5kg, held 20, 30, 40, or 50cm high, that is guided down a track to reproduce the same impact each trial (Figure 1). The pendulum apparatus mimics the impact that may occur when an athlete is kicked during a game. Results from these studies show that shinguards were effective in reducing force 40-60%.[3,12,17,24] It also shows that popular shinguards in terms of comfort, fit and playability performed worse in impact testing.[17] This is likely because while soccer players prefer lighter and smaller guards the heavier and thicker guards can attenuate more force, have longer dwell times, and reduce more strain.[12]

Evidence supports that shinguards are effective in reducing injury from impacts because the number of fractures in soccer has decreased from 24.7% of all injuries in 1988-1990[27] to 17.6% of all soccer injuries from 1990-1994[28] and down to 9.8% from 1998-2001.[1] These numbers correspond to the inception of shinguards as mandatory protective equipment in soccer games by FIFA, in 1990.[1] The quality and materials of the shinguards has also improved during this time period.

For safety reasons, shinguards are an important factor in the game of soccer. Because they are used in every practice and game, they are constantly being impacted by the ball, other players and the ground. Over time the impacts absorbed by the shinguard during practices and games could weaken the material. The plastic can crack or the foam can wear out. When the shinguard is no longer helpful in reducing injury the user must be aware of that in order to get a new pair. The purpose of this study is to determine if the amount of usage that a shinguard gets over time is detrimental to its ability to dissipate force.

METHODS

Subjects

Thirty six subjects from three different female soccer teams volunteered for this study. The participating soccer teams were a Division I women's intercollegiate soccer team from a large university, a high school varsity and junior varsity female soccer team, and a female youth team from a club soccer organization. Twenty seven subjects completed the study, 14 from the older age group, Division I and high school, and 13 from the younger age group, youth club team (Table 1). There were nine participants that did not complete the study. Reasons for not completing the study were that the shinguards were lost (n = 2), they didn't fit to the athletes liking (n = 2), they moved around too much (n = 1), they weren't comfortable (n = 2) and they couldn't be collected at the end of the study (n = 2).

Participants were included in this study if they were female athletes from the aforementioned teams and healthy in which they participated in and wore the shinguards for 80% of the season's practices. The exclusion criteria were any athletes who didn't participate in or wear the shinguards in 80% of the season's practices, any athletes who lost a shinguard, or who wore their shinguards at events outside of the stated team. Attendance of the participants was documented by the athletic trainer or coach for each practice. Injury, illness, vacation, forgotten shinguards, and any other reason for the shinguards not being worn in practice was counted in the 20% of the season they were allowed to miss.

Each group of athletes, collegiate, high school and youth, were given a pair of correctly fitted shinguards (Adidas adi) according to specifications by the manufacturer (Figure 2). They were asked to wear the shinguards for every practice and game for the stated team only for one season, including pre-season and post-season. Before participating in the study, parental consent was obtained for those subjects under 18, while those over 18 were given an approved Study Information Sheet. The University's Institutional Review Board for the Protection of Human Subjects also approved the study.

Procedures

Baseline tests of all shinguards occurred before distributing them to the participants. Shinguards were labeled with an identification number and letter code and then disseminated to the teams. The right shinguard was labeled A and the left was labeled B for all shinguards. Shinguards were then collected from the teams and tested on four occasions: ¼ of the way through the season, ½ through the season, ¾ of the way through the season, and following post-season. There were several pairs (n = 15) of control shinguards of different sizes which were not used by any of the participants, but were only tested on each occasion.

Force Absorption Testing

To test the shinguards, a drop track, similar to the ones used by Francisco[12] and Lees[24] was used in this study. The drop track consisted of a 5kg weight which was manually dropped from a height of 40cm. Attached to the weight was an accelerometer (Biopac Systems, Inc, Tri-Axial SS26-2, Goleta, CA). Each shinguard was placed on a model leg according to manufacturer's directions and secured using the shinguard fixation straps. The model leg, which was a wooden banister shaped like the lower leg, with the shinguard attached, sat on the floor and was held in place by Velcro and a fifty pound weight on each end (Figure 3). The 5kg weight was dropped from the top of the drop track onto the center of each shinguard five times on five separate occasions for a total of 25 hits on each shinguard. Data on the X, Y, and Z axis of the accelerometer was recorded. Only data from the Z axis, the vertical axis, was used for statistical analysis. Following each testing session, the shinguards were returned to each team before the next practice was held. No shinguards became cracked during this study.

Data Processing

The dependent variable evaluated in this study was dwell time (msec). Dwell time is the amount of time the weight is in contact with the shinguard during each impact. It represents the time that it takes for the weight to slow down and come to rest before changing direction. Dwell time was used in previous studies by Lees et al[24] and Francisco et al.[12] Two or more acceptable trials were used for statistical analysis. Twenty seven percent of all test sessions had two acceptable trials, 36% had three acceptable trials, 28% had four acceptable trials, and 9% had five acceptable trials. Therefore an average 3.2 acceptable trials were used per testing session.

Statistical Analysis

A repeated measures ANOVA was used to identify any changes between testing sessions. The within subjects factor was time at five levels (pre-test, ¼, ½, ¾, and post-test). The between subjects factor was group at three levels (older, younger, and control). A priori alpha level was set at $p<0.05$.

RESULTS

The RMANOVA revealed no significant time by group interaction ($F_{8,244}$ =0.56, p = 0.81, ES = 0.02, power = 0.26) (Table 2, Figure 4). There was also no significant difference between testing sessions, ($F_{4,244}$ = 2.15, p = 0.08, ES = 0.03, power = 0.63), or between groups ($F_{2,61}$ = 0.34, p = 0.72, ES = 0.01, power = 0.10).

DISCUSSION

The primary finding in this study is that the dwell time of an impact is not significantly different between used shinguards and un-used shinguards through the course of one season. The results of this study show that these shinguards do not change significantly or degrade throughout one season.

Results of this study were similar to those of Lees et al[24] and Francisco.[12] The current study had a dwell time of 20ms without a shinguard and an average of 37ms with a shinguard. These numbers are slightly higher compared to previous studies which reported a dwell time of 13-15ms without a shinguard and 18-19ms with a shinguard.[12,24] An increase in dwell time allows more force to be dissipated across the shinguard. The shinguard materials allow the impact to be dissipated over a larger period of time which can reduce the impact force 40-60%.[24] Lees et al[24] reported a 30-40% increase in dwell time when using a shinguard. The current study had an 85% increase in dwell time; therefore, according to previous literature we found a substantial reduction in force by using the shinguard. This difference in dwell times between previous literature and this study could be explained by a difference in shinguards and their materials or the model legs used in the different studies. The Adidas Adi shinguards used in this study had a rigid outer shell with a foam backing and a compressed air bladder in the center. The outer shell is made of 100% polypropylene. The foam padding is made of 83% ethylenevinylacetate (EVA) and 15% polyethylene. The shinguards have two straps one at both the top and bottom of the shinguard. It also has a removable ankle guard made of 50% polyester and 50% rubber. Reasons for choosing this type of shinguard for this study were the light and durable front outer shell, the fit foam, detachable ankle guards for additional protection, and two fixation bands. These shinguards were also a good match for all age groups involved in this study. Previous work did not use shinguards with a compressed air bladder[24] and the shinguards used may have been of poorer quality as they were considered medium to low cost shinguards. However, Lees[24] did perform testing using a wooden leg model[24] while Francisco[12] studied compressed air shinguards using a synthetic bone surrounded by rubber covered foam as the model leg. These difference could be potential reasons for the differences in dwell times reported. The increased dwell time of this study compared to previous literature may also show that the quality of soccer shinguards has improved in the past 10-15 years. A better quality shinguard with more foam should have an increased dwell time because there is more cushion to slow down the weight on impact.

Any reduction in impact by a shinguard can greatly reduce the risk of injury and possibly fracture.[1] This is why larger shinguards, with more materials, may provide better protection for the soccer players.[12] Larger shinguards with more foam provide a greater area for force to be dissipated.[12] The dissipation of force over the entire shinguard instead of just over one spot on the shin can help reduce abrasions from soccer shoes as well as cleat marks and contusions on the shin. It is possible that shinguards may help to reduce fractures although the shinguards are not designed to stop fractures from occurring and the manufacturers do not claim that they can reduce fractures or serious injury from impacts during soccer.

When the weight was dropped on the wooden leg without a shinguard the dwell time was 20ms. If the dwell time with a shinguard was getting smaller or closer to 20ms throughout the season, it would have indicated that the shinguards were possibly getting worse or degrading. However, the dwell times of this study for each testing session averaged 38ms, 39ms, 35ms, 39ms, and 36ms respectively across all five testing sessions. This shows that the foam and plastic were not degrading over time and the shinguards were able to protect the shin just the same from the beginning of the study to the end.

Length of the study period was a limitation of this study. Due to time constraints this study had to be completed over the course of only one season, or three and a half months. Most soccer players will typically wear shinguards for one or two years before replacing them. Had there been more time, this study could have been completed over a full two years and there may have been different results. Another limitation was that only one type of shinguard was used in this study. There are thousands of different kinds of shinguards on the market today. Not all of them have the same materials or force dissipation capabilities as the one we chose to use. Therefore, our results may not translate to all shinguards because each shinguard may react differently to the stresses placed upon it. Finally, only female subjects participated in this study. Impacts in soccer for males above the youth level can be much greater than for females. The results of this study may not convert to males because they kick with a much higher force then females. Multiple impacts of greater force may lead to broken or degrading shinguards at a faster rate. It also would have been very difficult to find high school and collegiate male soccer players that would wear a properly sized shinguards.

Currently there is no research regarding why soccer players, especially at the collegiate level, don't like to wear shinguards. Based on experience, I have learned that in collegiate soccer the thought about shinguards among the athletes is that smaller is better. Shinguards must be lightweight and small yet durable. Soccer players claim that shinguards are uncomfortable and they get in the way of ball control. Also, if they are too heavy they may make the athletes legs feel heavier when running and tire more quickly. Lastly, shinguards can move around a lot especially if they are not strapped to the leg. This can cause discomfort to the athletes and can be distracting because they will have to continue adjusting the shinguards during the run of play. For these reasons it is difficult to get a collegiate soccer player to wear a properly sized shinguard, however, it is most important at this level because of the force with which they can kick.

Shinguard degradation is based on the quality of the materials, how many impacts they sustain and how hard the impacts are. These impacts can vary by position on the field,[9,29] males or females,[2] leg dominance,[2,9,30] and experienced or non-experienced players. Because there is little research regarding shinguards there are several areas where future research is needed. Further research is important in order to protect the millions of soccer players in this country and around the world.

Most soccer players wear shinguards for one or two calendar years. Because of this a study of similar nature to this one but over the course of multiple seasons may be more beneficial in determining when shinguards wear out. The typical shinguards available on the market today are polypropylene, plastic, foam, thermoplastic or fiberglass moldable shinguards, compressed air, and Kevlar.[12] In comparing the different types based on principle strain, impulse, and contact time, Francisco et al[12] found that there was no significant difference between the types of shinguards, when looking at dwell time, but they identified a trend which pointed to compressed air being the most effective.[12] The materials that the shinguards are made from may degrade over the course of multiple seasons due to sweat, extreme weather conditions, impacts, and time. This can lead to cracking of the plastic or fiberglass or decreased cushion of the foam. The compressed air pocket may also become deflated. Over multiple seasons the shinguards may show more wear, thus, showing when they need to be replaced.

Future research can also look at limb dominance and shinguard wear. Due to the dominant limb being more involved in jumping, landing, turning, kicking and tackling, it is a factor in the injury rate.[7,9] Previous research shows that 54% of injuries occur to the dominant limb and only 34% occur to the non-dominant limb.[7,9] This extra exposure of the dominant limb may result in the shinguard getting impacted much more than the non-dominant limb possibly having an effect on shinguard wear and degradation.[2,8]

Conclusion

Based on the findings from this study shinguards don't degrade over the course of one season. It has yet to be determined how long it takes for shinguards to degrade to the point when new ones are warranted aside from being broken, deformed, torn or missing any parts. Manufacturers guidelines for the shinguards used in this study do not specify a definitive period of use that shinguards are good for. There isn't a quantification of how long the shinguards will last or when to buy a new pair. To prevent injury in the collegiate setting, soccer teams can and should provide shinguards for the athletes every year to help decrease the chance of a shinguard becoming worn out. Youth players should follow manufacturers guidelines and replace shinguards if they are broken, deformed, or missing parts. Based on the findings from this study it cannot be said that shinguards should be replaced every year but the athlete should use good judgment when the shinguards appear to be worn out or broken.

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Table 1: Age, years of experience, and position

Group (n)	Average age (yr)	Years of experience (yr)	Position (n)
Older age group (14)	16.00 ± 2.29	6.35 ± 6.00	Defense (4) Midfield (7) Forward (3)
Younger age group (13)	8.70 ± 0.47	3.10 ± 1.66	All positions (7) Defense (1) Midfield (3) Forward (1) GK (1)

Table 2: Dwell time means and standard deviations for testing sessions (ms)

	Pre-season	¼ season	½ season	¾ season	Post-season
Older	38 ± 08	37 ± 10	34 ± 07	38 ± 07	38 ± 12
Younger	37 ± 12	40 ± 12	34 ± 05	40 ± 10	35 ± 10
Control	38 ± 11	39 ± 09	37 ± 12	39 ± 09	35 ± 08

Legend of Figures

Figure 1. Drop Track Apparatus

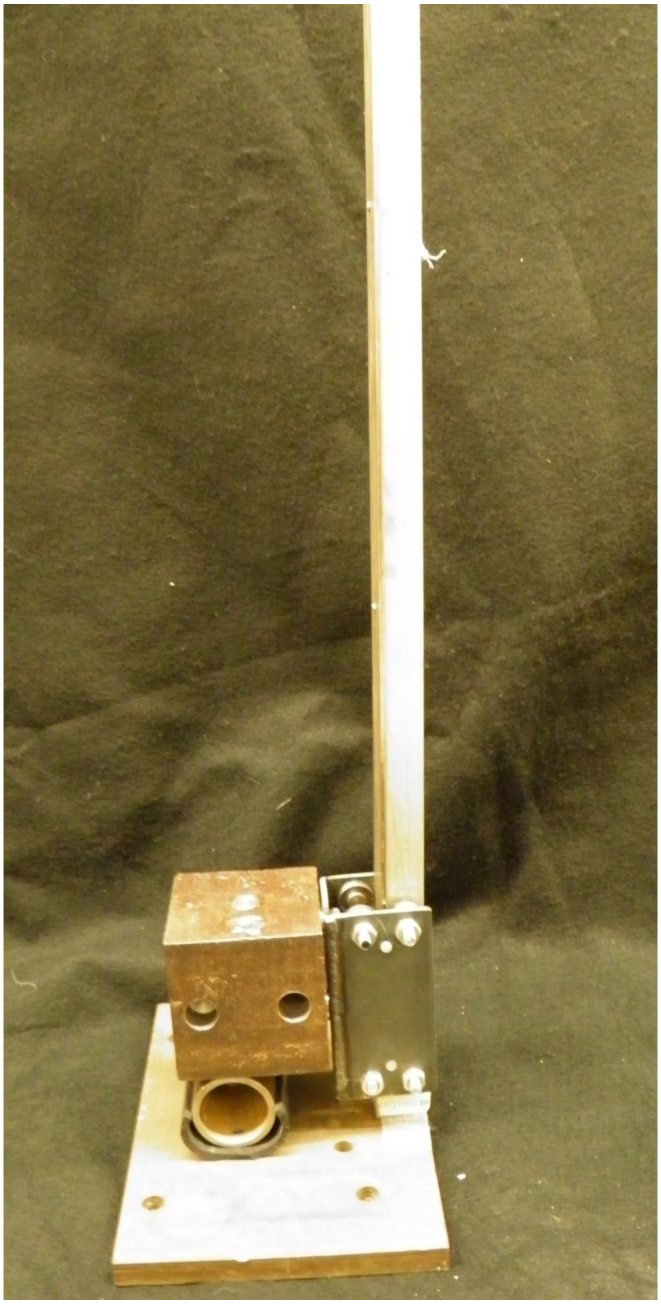


Figure 2. Adidas Adi shinguards

Figure 3. Drop track with weight and accelerometer attached and wooden model leg with shinguard attached.

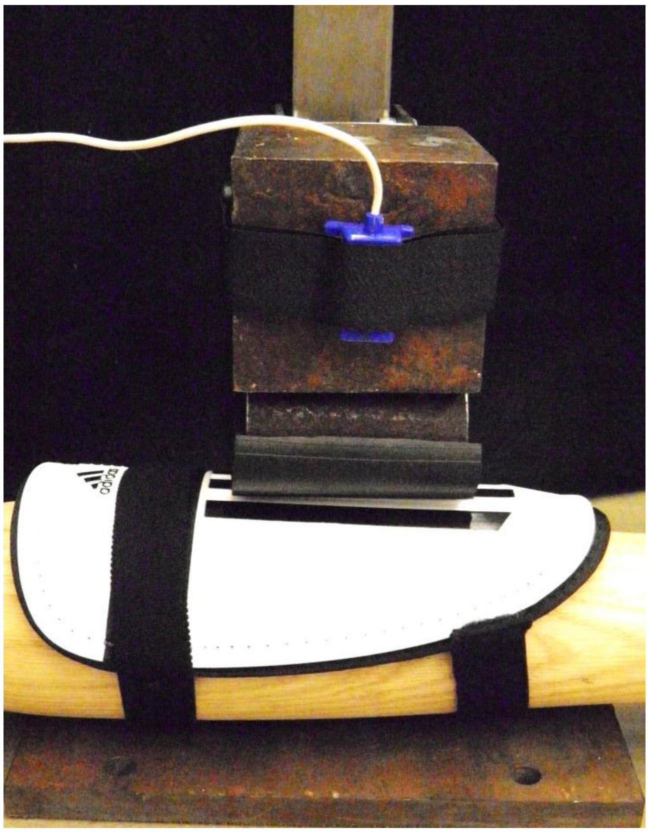
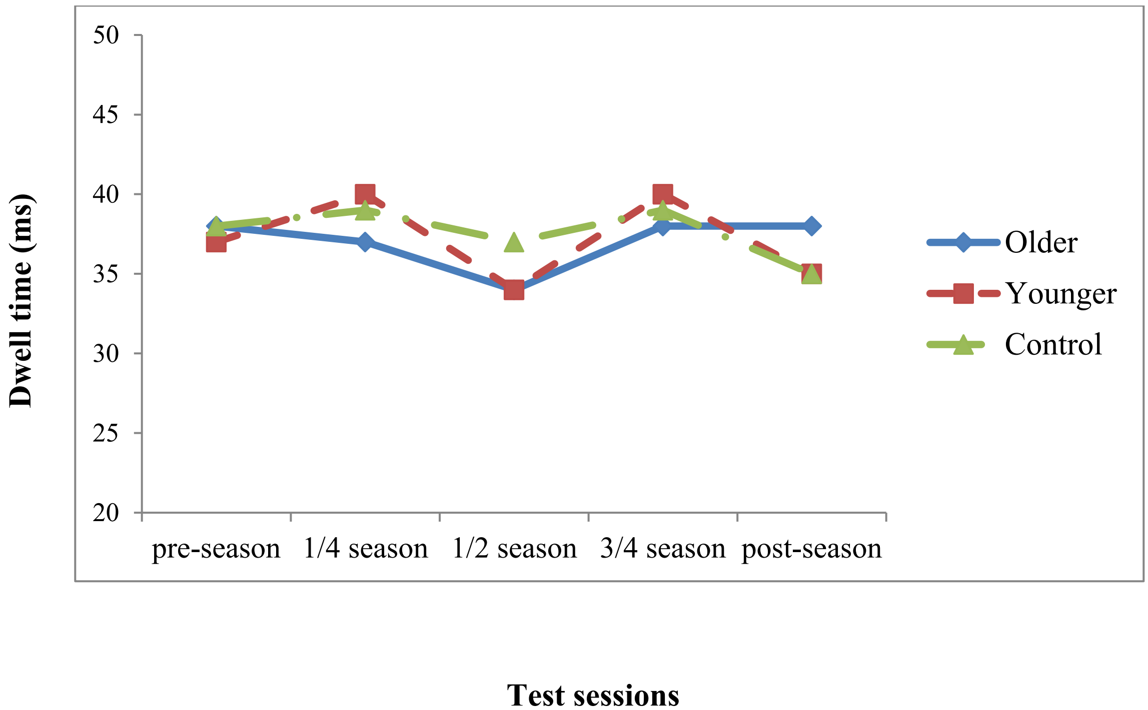


Figure 4. Line graph of mean dwell times of the five testing sessions for all three groups



APPENDICES

APPENDIX A

Operational definitions

Assumptions

Delimitations

Limitations

Statement of the Problem

Independent Variable

Dependent Variable

Research Hypothesis

Operational Definitions

1. Acceptable Trial: All phases of the impact are clearly recorded by the Acqknowledge Software.
2. Adidas Adi Shinguard: A shinguard with a hard rigid outer shell and soft foam backing. It is light and durable, has fit foam, detachable ankle guard and two fixation bands.
3. College Athlete: a Division I female soccer player.
4. Control Shinguard: A shinguard which is only subjected to the weight being dropped on it over five test sessions, it is not used by any participant.
5. Drop Track: a free standing device that consistently drops a 5kg guided weight from a height of 40cm.
6. Dwell Time: the amount of time the weight is in contact with the shinguard during each impact.
7. Healthy: The participant plays in at least 80% of the season's practices.
8. High School Athlete: female athletes on a local high school varsity or junior varsity soccer team.
9. Occasions of participation: any mandatory practice or game that happens during the season.
10. One Season: a three month time period when practices and games are happening consistently. Pre-season training and post-season games and training will also be included.
11. Protective Equipment: a device used in sports to protect an area from injury.

12. Shinguards: a protective device made of a hard rigid outer shell and a soft inner foam layer, usually made to fit the contour of the leg. It is placed over the shin to reduce injury to the shin.[21] Adidas adi shinguards will be used.
13. Unacceptable trial: a test in which the shinguard or model leg moves out of place upon impact or an error with accelerometer data.
14. Youth Club Athlete: female athletes who participate on the local club soccer team at ages 7-10.

Assumptions

The following assumptions will apply to this study:

1. The coach will mandate the use of shinguards for each practice and game.
2. Participants will wear the shinguards in each practice and game.
3. Shinguards will not be worn outside of said team practices and games.
4. Athletes will be truthful in the amount of shinguard use.
5. Collegiate athletes will use the shinguards 20 hours/week, high school athletes will use the shinguards ten hours/week, and youth athletes will use the shinguards six hours/week.
6. All collegiate female soccer training is similar to other Division I schools, high school training is similar to other high schools, and youth soccer training is similar to other youth athletes.

Delimitations

The following delimitations apply to this study:

1. The participant must be a Division I soccer player, high school varsity or junior varsity soccer player, or youth soccer player age 7-10.
2. All athletes will be female.
3. Adidas adi shinguards will be used by all participants.
4. All participants will be between the ages of 7-22.
5. Testing will be performed before the season on all shinguards and four other times throughout the season: ¼ of the way through the season, ½ through the season, ¾ of the way through the season, and after post-season is complete.
6. Athlete must complete 80% of the season's practices.

Limitations

The following limitations will apply to this study:

1. Athletes may get injured and not be able to wear their shinguards because they can't participate in practice or games.
2. An athlete may lose or break her shinguards.
3. The study must be performed over the course of only one season.
4. Only Adidas Adi shinguards will be used.
5.

Statement of the Problem

Many studies have been done on the ability and effectiveness of shinguards to dissipate force. All of these studies show that shinguards are successful in reducing injury, however, none of these studies show how long shinguards are effective. When a shinguard is no longer helpful in reducing injury the user must be aware of that in order to get a new pair. The purpose of my study is to determine if the amount of usage that a shinguard gets over time is detrimental to its ability to dissipate force correctly.

Independent Variable

One independent variable will be evaluated in this study:

1. Time @ 5 levels

    a. pre-season

    b. ¼ of the way through the season

    c. half way through the season

    d. ¾ of the way through the season

    e. post-season

Dependent Variable

One dependent variable will be evaluated in this study:

1. Dwell Time (ms)

Research Hypothesis

There will not be a significant difference in pre-season and post-season dwell times of shinguards.

Statistical Hypothesis

1. Dwell Time: H_a: $\mu_{T1} \neq \mu_{T2} \neq \mu_{T3} \neq \mu_{T4} \neq \mu_{T5}$

Null Hypothesis

1. Dwell Time: H_o: $\mu_{T1} = \mu_{T2} = \mu_{T3} = \mu_{T4} = \mu_{T5}$

APPENDIX B

Review of Literature

Soccer is a sport that is played by millions of people throughout the world.[1] Because the sport is so prevalent, many injuries occur, especially to the lower extremity.[3,4,6,7] The shinguard is designed as a protective device to shield against impacts to the shin. [12,14-16,22,24] The accepted method for testing the force dissipation capabilities of shinguards is with the use of a drop track or pendulum instrument to produce a force on the shinguard being tested.[12,17,21,24,25] Related to this topic the following ideas will be included in this review of literature: 1) lower extremity injuries in soccer, 2) protective equipment used in soccer, 3) shinguards as protective equipment and shock absorbers, and 4) methods for testing shinguards.

Lower extremity injuries in soccer

Poor field conditions, foul play, inadequate training, and protective equipment are all factors associated with soccer injuries.[31] One third of all medically treated sports injuries each year are from soccer.[3] There are more injuries in games than in practice in the older age groups, (ages 14-19 years),[2,4] while in the younger age groups, (under 14 years), injuries are more likely to occur in practice.[19] Ekstrand et al[32] found that there was on average one injury every third game and one injury every ninth practice showing that injuries are three times a likely to occur in games. In all age groups, the majority of injuries, 60-87%, are to the lower extremity and caused by player to player contact and injury occurrence increases with age. [2-10,33] Fifty nine percent of traumatic injuries are caused by direct contact between players with more contact injuries happening in the younger age groups then the older. The primary injuries seen in a review of NCAA men's soccer injury data were sprains, contusions, and strains.[4,10] Hawkins et al [6,7] and Price et al[9] found strains to be the most prevalent injury at 31-37%, sprains at 20-21% and contusions at 16-24% of all injuries, whereas, Maehlum et al,[5] found 47% of all injuries in soccer to be contusions, 22% were sprains, and 18% were lacerations. Limb dominance is also a factor in the injury rate with 54% of injuries occurring to the dominant limb and only 34% occurring to the non-dominant limb.[7,9] This is due to the dominant limb being more involved in jumping, landing, turning, kicking and tackling resulting in more exposure and ample opportunity for injury.[2 8]

Thirty percent of the medically treated soccer injuries are fractures of the lower leg.[3] The majority of these fractures happen when one player kicks another.[3] Slide tackling results in more injuries then any other form of contact.[11,34] One study[34] suggests slide tackles with medial and lateral impacts cause many more injuries than slide tackles with an anterior or posterior impact. Also, impacts from a slide tackle during weight bearing caused greater injury with a longer time loss.[34]

Protective Equipment

With the use of protective equipment many minor injuries such as contusions can be prevented[23] and the severity of sports injuries can be reduced.[3] Protective equipment must meet certain required standards and it must not be altered at any time.[23] When protective equipment is altered or shifts from its correct position on the leg it is no longer helping the athlete, and it may cause more damage to the athlete.[23] It is up to the coach, athletic trainer, manufacturer and team physician to teach the athlete about proper use of protective equipment.[23] Athletes are more often injured because of the improper fitting of the protective equipment not improper manufacturing of the equipment.[35] This improper fitting may be the biggest danger an athlete faces when using protective equipment.[35]

Properly fitting protective equipment is one way to prevent injuries.[20] Ellis[20] describes eight ways in which to protect oneself from injury utilizing protective equipment. One should 1) buy the protective equipment from a trustworthy manufacturer, 2) buy the best and safest equipment that resources will allow, 3) properly fit the equipment according to manufacturers directions 4) maintain the equipment according to all recommendations by the manufacturer, 5) only utilize the equipment for its intended purpose, 6) warn all participants using the equipment of inherent risks involved with the use, misuse, or malfunction, 7) use extreme caution in constructing or altering sports protective equipment for an athlete, and 8) not use any protective equipment which is defective in some way. Many sports teams struggle with compliance in wearing protective equipment because some coaches don't mandate that their athletes wear the devices or know how to fit them properly. Ultimately, it is up to the coach to enforce compliance during practice.[20]

Shinguards as a protective device

Lower leg protection in the game of soccer is accomplished by the use of shinguards.[3] Shinguards are designed to cover the anterior shin reducing injury to the underlying skin tissue and possibly the tibia.[3] They function best when they are worn between the middle and distal third of the tibia.[13] Shinguards have little effect on reducing injury to the ankle, knee, or fibula because they do not cover these areas.[3] Inadequate or no shinguards have resulted in traumatic leg injuries in soccer.[20] It is mandatory that shinguards be worn by soccer players in games in order to protect the shin area from direct contact by another player or object.[24] Based on the high rate of injuries in soccer and the potential for shinguards to reduce the prevalence of these injuries they became mandatory in 1990 by Fédération Internacionale de Football Association (FIFA),[1] but they were not regulated as to the proper size one should wear or of what material they should be made with.[4] Agel et al,[4] reported no immediate or recognizable reduction in ankle or lower leg injuries from the three previous years before shinguards were mandated to the following ten years after they became mandated. This may be the result of when athletes wear protective equipment they are likely to play more aggressive injuring themselves or others resulting in no change of injury rates.[35] Shinguards are normally made from a rigid outer shell of polyurethane and a softer inner layer which is thermoplastic.[3,14,15] There are three basic shapes of shinguards and several materials they are made from.[3,12] The first is a shinguard with a curved hard shell and a smooth surface, second is the same curved hard shell but with a profiled surface, and third is a shinguard with non-continuous outer shell that consists of long small strips of hardened material held in pockets on the guard.[3] The typical shinguards available on the market today are plastic or foam, thermoplastic or fiberglass moldable shinguards, compressed air, and Kevlar.[12] In comparing the different types based on principle strain, impulse, and contact time there was no significant difference between the shinguards, but they identified a trend which pointed to compressed air being the most effective.[12]

The shinguards should sit on the skin partially surrounding the leg.[14,15] The inner layer is often made of ethylenevinyleacetate or polyurethane foams.[14,15] For optimal protection, shinguards should cover the malleoli and the tibial crest.[20]

Shinguards act as shock absorbers

Shinguards, when used correctly, are intended to reduce punctures, contusions, lacerations and any other soft-tissue pathology across the shin area.[16,22] These protective devices have been proven effective in reducing force directed at the shin from balls, legs, and cleat studs.[3,12,14-16,22,24] Shinguards reduce injury by acting as shock absorbers as they spread the load across a larger area, modifying the shock absorption characteristics of the lower leg.[14,15,24] They also can deflect the energy back to the striking force.[24] Results from previous research show that the impulse from a force is dissipated across the shinguard reducing the total impact force on the tibia.[24,25] Shinguards are shown to be effective in reducing force by at least 40%,[3,12,24] while other research has shown a decrease in force of up to 77% that is transferred through the guard.[25] One shinguard, Air Lotto Italia, was able to reduce forces from 2320.6 N on an unprotected leg to 531.33 N with a protective shinguard.[25] Lees et al[24] looked at the energy return of a shinguard meaning how much energy rebounded off the guard and how much was absorbed into the leg model. Without a shinguard the leg model absorbed 70% of the energy from the dropped force and only returned 30% through rebound. With a shinguard, 40-50% of the energy was returned through rebound leaving 50-60% to be absorbed into the leg.[24] They found a decrease in energy absorption of 10-20%.[24] Lees et al[24] and Francisco et al[12] both studied dwell or contact time. Both studies found that the dwell time was increased with a shinguard compared to no shinguard.[12,24] Dwell times of an impact can be increased by 30-40% with the use of a shinguard.[24] This allows the impact to be dissipated over a larger period reducing the magnitude of the impact by 40-60%.[24] Mean dwell times with a shinguard previously reported were 17ms and 19ms and without a shinguard they were 13ms and 12ms by Lees et al[24] and Francisco et al[12] repectively. Previous research agrees that soft tissue injuries are greatly reduced by the use of shinguards.[4,16,17,24] In addition, one study suggests that shinguards reduce the risk of fracture to the lower extremity,[12] however, another study suggests that only with an improvement in shinguard quality and design may the tibia and fibula be better protected from fracture.[16] Lees[14] argues that shinguards don't contain enough material to absorb a large quantity of energy from a single blow.[14,24] All energy is either transmitted to the structures being hit such as the shinguard and leg or it is reflected back to the striking component causing a rebound effect.[24] However, one might argue that any reduction of forces can prevent injuries that may occur without the use of shinguards.[25]

Shinguards are not only hit by direct contact from two players hitting each other but also from ball contact. Paris[36] found that when just a ball is dropped onto a force plate from 14 different heights the force can be extremely high. If the ball is traveling at 13.9 m/s the calculated force production is 1939 N.[36] If a maximum kick is 2300N[25] then dropping a soccer ball produced a force which was 81-84% of the force from a maximal kick.[14,25] Additionally, the force from the ball can change depending on the mass, pressure, radius, and binitial velocity.[36] Zernicke[37] estimates that a high level male soccer player can kick a ball with a ball speed of 20-30 m/s which suggests a greater force production than 1939 N. The shinguard must not only dissipate force from being kicked but also from a ball being kicked at the shinguard.

The level of protection of a shinguard varies between different sizes, weights, shapes, and brands.[17] Heavier guards are able to dissipate more force and reduce the strain better than smaller lighter shinguards.[12] Due to anatomic differences each player has their own preference in shinguards.[17] Hume et al,[17] tested shinguards on the basis of perceptions of protection, comfort, fit, breathability, playability, support, and appearance. Their research suggests that perceived comfort of shinguards affects whether they will be worn or not. Surprisingly, what they found was that the more comfortable the shinguard was the worse it performed in impact testing.[17] This is likely because many soccer players prefer using lighter, less bulky guards to thick, heavier ones.

Method for shinguard testing

The National Operating Committee on Standards for Athletic Equipment (NOCSAE) requires testing of shinguards before they can be used for high school play. Shinguards have been tested in various ways in the past. A drop track apparatus has been used in most studies[12,17,21,24] others have used various other impact devices including a pendulum apparatus to imitate the kicking motion,[25] and swinging of a hockey ball[3], as well as a spring loaded guided impactor with a wooded spherical head.[3] Each of these methods simulates low impact velocities.

When using a drop track, a 4.2-7.5 kg weight impactor is dropped from a height of 20, 30, 40, or 50 cm onto the center of the shinguard.[12,17,21,24] An accelerometer which is attached to the impactor device can calculate and record the dwell time at impact. In addition, the base of the weight contains a rubber guard which comes in contact with the shinguard to simulate an opposing player's shoe.[12,17,21,24] One impactor had a cleat stud attached in order to produce a more real life impact.[22] Each shinguard was attached according to manufacturers instructions to either a model leg made of wood,[24] rubber covered foam,[12] or a leg anvil.[21] The weight was dropped onto the model leg before the shinguard was attached for a baseline reading and then each shinguard was tested 3-10 times and data were recorded.[3,12,17,21,24]

The pendulum apparatus to recreate the kicking motion was designed to create 2,300N of force upon impact of the shinguard.[25] The swinging pendulum was 34 inches long and a steel pipe acted as a foot for consistent loading. The shinguard was attached to a crash dummy leg model which had load cells attached to the knee and ankle so the data could be recorded.[25] This set up is more realistic in soccer when one player kicks another.[25] The hockey ball pendulum device with a mass of 0.159 kg had a maximum impact velocity of 3.6 m/s which was determined by an accelerometer.[3] In this model the shinguard was attached to a wooden cylinder with a diameter of 100 mm and length of 300 mm.[3] With this design the shinguards were tested at 2.5 m/s and 3.6 m/s. At 2.5 m/s they found a decrease in peak impact force of 60-90% with nine different shinguards. The same shinguards were tested at 3.6 m/s and there was a force decrease of 40-81%.[3]

Finally, the spring loaded guided impact device had a wooden ball shaped face, a diameter of 164 mm, and a mass of 6.8 kg.[3] It created a much larger impact velocity then the hockey ball test setup.[3] The maximum velocity was 6.7 m/s but it was decided that a velocity of 1.25 m/s was sufficient so not to damage the wooden shinguard support or impactor.[3] Again, an accelerometer was attached to record the velocity.[3] Seven shinguards were available for this study and the results showed a peak force reduction of 28-53%.[3]

Dependent variables differentiate these studies from one another. One study[24] tested the shock attenuating effectiveness of shinguards by looking at the peak deceleration and energy return of the weight on the shinguard. They had peak decelerations of between 42-63 g and energy returns between 40-51%. They also compared the price factor of the guards. Results showed that the price was not a factor in whether shinguards were able to effectively reduce force.[24] Expensive shinguards did not protect the shin better then cheap ones. Multiple studies[12,24] reported dwell or contact times using an accelerometer. The dwell time is the amount of time the weight is in contact with the shinguard. They found reductions in impacts to be 40-

60%.[12,24] Shinguard testing was also done using an accelerometer and a load cell to determine the efficacy in protecting the tibia from fracture.[12] Shinguards may reduce the impact enough to decrease the incidence of fractures but they will not stop all fractures from occuring.[12] The study by Ankrah et al[22] used flexible force sensors to show that the shinguard's edges lift upon impact with a cleat stud which leaves a gap between the leg and guard.[22] One shinguard buckled during this kind of impact of only 696N. To reduce this deformation, the transverse bending stiffness must not be too rigid. The shinguard should bend against the curvature of the leg.[22] Furthermore, testing was completed to determine perceived comfort of shinguards and how that related to their ability to decrease force upon impact.[17] As previously stated, shinguards which showed a decreased ability to dissipate force were perceived to be more comfortable by the athletes.[17]

Some research questions the ability of shinguards to protect against fractures once an unknown force has been applied stating that 90% of fractures in their study occurred while shinguards were worn.[16] They also stated that the shinguards were in the correct place in all athletes but contact was only made on the shinguard in 16 cases while in 15 cases the contact was medial or lateral to the guard.[16] Other studies show that shinguards do protect against fractures of the tibia in some cases.[12,16] Impacts from a tackle or direct contact accounted for 95% of tibial fractures in two studies.[1,18] From 1988-1990 an estimated 24.7% of all soccer injuries were fractures,[27] from 1990-1994 that number went down to 17.6%[28] and from 1998-2001 it was down even further to 9.8%.[1] These numbers correspond to the introduction of shinguards and better design and improvements in quality and usage.[1]

Conclusion

In conclusion, shinguards are a necessary form of protective equipment in the game of soccer whether the athlete likes to wear them or not. Previous research has demonstrated their ability to decrease force upon impact by a ball, shoe, or cleat stud.[12,14-16,22,24] This form of protective device has reduced the number of fractures seen in soccer since its inception in 1990 and countless other injuries have been prevented.[1,27,28]

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